Polymer Compounding and Blending

(PPE-316)

Assignment On Pipes for Hot Fluids

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Introduction:

Hydronic heating is a popular method of heating used, particularly due to its effectiveness. Water's superior heat holding capacity compared to air makes it an ideal medium for distributing heat throughout your living space.

In a hydronic system, a boiler heats water, which then circulates through radiators or underfloor pipes to warm your living space. The heat radiates from the water, creating a comfortable and natural room climate. This technology offers two different systems between boilers solely for heating, or combined boilers for hydronic-heating and domestic hot water supply.

Hydronic heating systems are common in many countries around the world, particularly in regions with colder climates where efficient and effective space heating is crucial. Some of the countries where hydronic systems are widely used include:

- **Canada:** Common in colder provinces like Alberta, Saskatchewan, and Manitoba to combat harsh winters.
- **Scandinavia**: Norway, Sweden, Finland, Denmark (due to long, cold winters and well-developed infrastructure)
- **Germany:** Known for its energy-efficient approach to heating, often utilizing hydronic systems with boilers or heat pumps.
- **Austria and Switzerland**: Popular in these mountainous regions due to their ability to effectively distribute heat across uneven terrain.
- **Eastern Europe:** Countries like Poland, Czech Republic, and Slovakia rely heavily on hydronic heating due to affordability and effectiveness.

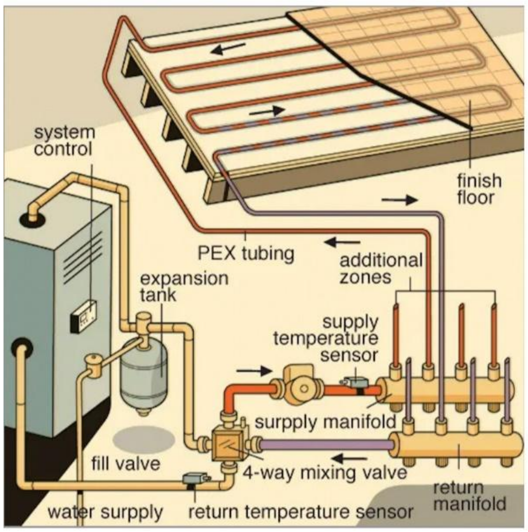

Figure 1:Scheamatic Diagram of Hydronic Heating System.

This manuscript particularly focuses on the manufacturing of pipes or tubing for radiant heating systems, specifications or properties of the pipes required for this application, along with the properties expected by the prepared blend, preparation of the blend from constituent polymers and processing equipment required also the processing conditions to achieve desired morphology and the reason for selection of the specific constituent polymers and the particular blend for this specific application.

In order to prepare blend for this application we need to pay our attention to the properties required for intended application covered in the following section.

Specifications Required:

Freeze Break Resistance:

The flexibility of the pipe must allow it to expand as water freezes in the pipe as long as the pipe has room to expand. When the water thaws, the pipe returns to its original shape. If the pipe is not allowed to expand it may burst.

Hydrostatic Pressure:

Pipe's resistance to bursting under internal pressure. Pressure resistance must be higher than 50-Psi value obtained from TDS included in testing section.

Flexibility:

Pipe's must have high capability of bending to achieve spiral shape without plastic deformation and breaking included in testing section.

Figure 2:A Picture During Installation.

Vicat Softening Temperature:

VST > 95°C If VST would be lesser than application temperature then pipes would be subjected to inflation by hydrostatic pressure inside. Included in testing section.

Additional Properties Required:

- Resist pitting and stress corrosion.
- Resist scaling and deposit build-up when used with both hard and softened water.
- Minimize noise that is transmitted through pipes.
- Withstand the high temperatures and pressures of hydronic heating systems.
- Resist notching and abrasion damage[1].

Selected Constituents for blend:

PE-RT_ stands for Polyethylene Raised Temperature

PP_ stands for Polypropylene

Why to Choose/Prefer These Two as Constituents?

PE-RT:

PE-RT stands for Polyethylene of Raised Temperature resistance. It's a medium-density polyethylene (MDPE) specifically modified for improved heat resistance compared to standard PE. This makes it suitable for hydronic heating systems, where water temperatures can reach 60°C to ≈90°C.

Key Differences:

- HDPE: Offers superior strength, rigidity and heat stability but lacks PE-RT's flexibility as from the figure can be seen that flexibility is key factor to obtain spiral turns without the use of fittings (i.e., joints, elbows and tees).
- LDPE: Highly flexible but unsuitable for hot water due to its low melting point.
- MDPE: Gives balanced performance between flexibility and heat stability.

Table 1: Comparison Chart of Poly Ethylene.

Feature	PE-RT(MDPE)	HDPE (High-Density PE)	LDPE (Low-Density PE)
Heat Resistance	Excellent (up to ≈90°C)	Good (up to 90°C)	Poor (not suitable for hot water)
Flexibility	High	Moderate	High
Strength	Good	Excellent	Moderate
Cost	Moderate	Expensive	Most economical
Applications	Hydronic heating systems, potable water, some industrial applications	Pressure pipes, tanks, geomembranes	Food packaging, films, flexible tubing

Polypropylene (PP):

1. Molecular Structure
   - PP has a linear, isotactic, syndiotactic or atactic molecular structure, (isotactic and syndiotactic) contributes to its relatively high stiffness due to better arrangement of chains at molecular level.
2. Crystallinity
   - PP (iso/syndiotactic) has a higher degree of crystallinity compared to MDPE. Crystallinity is associated with stiffness, and PP's more ordered molecular arrangement contributes to its stiffness.
3. Amorphous and Crystalline Regions
   - PP has a significant crystalline structure, which results in well-defined regions of crystallinity and amorphous structure random chains regions both occupy particular volume.
4. Chemical Stability
   - PP is more resistant to some chemicals than PE, such as chlorine and bleaches.

Creating Blend:

Property Trade-offs:

While blending can offer a combination of properties, it often involves trade-offs. For example, improving flexibility may come at the expense of stiffness, and vice versa depending on the physical and chemical interactions between the both polymers.

Why to Blend:

For radiant heating system PEX is commonly being used/produced worldwide which is merely a crosslinked polymer of polyethylene now some rare producers supply PE-RT/PP blends for this particular application several reasons have potential for the switching or shifting from the virgin PE-Crosslinked to towards a blend of PE-RT with PP following are logical to be considered, i.e., PP is more resistant to some chemicals than PE, such as chlorine and bleaches. A-PP has a relatively high crystallinity of around 50-65%. This means a significant portion of its polymer chains are arranged in an ordered, crystalline structure, contributing to its rigidity and strength which further reducing the processing cost of crosslinking which is being carried out to enhance the stiffness of the article also in terms of the cost of resin (i.e., A-PP is cheaper than PE) further A-PP has better melt flow properties the an PE which helps to reduce the processing cost along with that.

Blend Composition:

80%MDPE – 20%PP

The commercialize compositions of the blends are kept confidential by the producers. This composition is decided or choose on the basis of our end requirement and expected participation of each component in the final properties of the blend.

In Terms of Miscibility:

PP and PE blends are compatible but thought to be only partially miscible. The polymer pairs tend to separate into two liquid phases. Each phase is a solution of a minor component in a major component and the phases separate into sub-microscopic domains. The polymer with the major proportion forms the continuous matrix and contributes most towards properties while the minor polymer forms small discrete domains, which contribute synergistically to certain specific properties. PP and MDPE are compatible polymers but they are thought to be only miscible at some compositions and at elevated temperatures. Most polyolefins are immiscible in the liquid state since small differences in the shape of the molecules give rise to unfavorable intermolecular forces. A further immiscibility arises as the polyolefins crystallize into different crystal domains.

Two important characteristics of the components need to be taken into consideration: whether they are thermodynamically miscible or mechanically compatible. Thermodynamically miscible polymers are homogeneous at the molecular level. The mixing process must produce a decrease in free energy (ΔG), $\Delta G = \Delta H - T\Delta S \leq 0$. This results in a single-phase polymer blend, at a specified temperature, and therefore the majority of the properties of the blend will be an average of the properties of the individual polymers.

DSC Graphs:

Following DSC graphs comparison will present the expected miscibility behavior of the constituents in the blend, as the simple rule more miscible will show average properties and both peaks of heat of fusion will move towards each other merge to give a single peak. Figure No.3 having less crystalline component (LDPE) blended with more crystalline (PP) showing components with to different level of crystallinity and amorphousity exhibiting immiscible behavior means not giving a synergetic gain of properties while in Figure No.4 having (HDPE) and (PP) both having quite considerable crystalline regions here the peaks are quite approaching each other but (HDPE) have more %age crystallinity than (PP) so still peaks are not much merging each other. So, we need to decrease the crystallinity of (PE) somewhere intermediate between (LDPE) and (HDPE) thats what known as PE_RT or (MDPE) preferred for having the properties of (HDPE) and more compatible morphology with (PP) a quiet synergetic gain in properties can be expected. In Figure No.5 the expected graph of DSC is presented showing a quite good merge in both peaks. Varying compositions and processing conditions can lead to further better morphology.(Note: 80%PE and 20% PP for all following DSC charts).

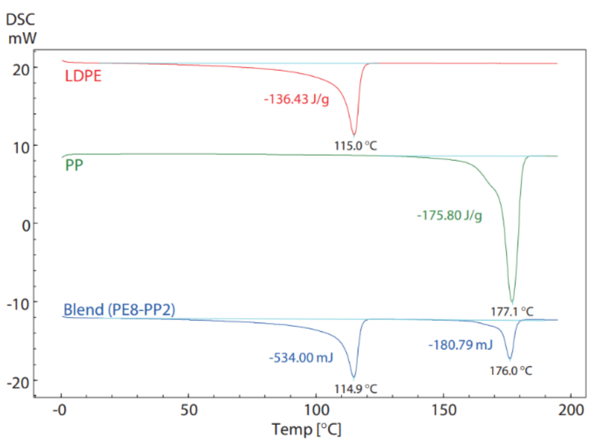

Figure 3:DSC-Plot of LDPE and PP.

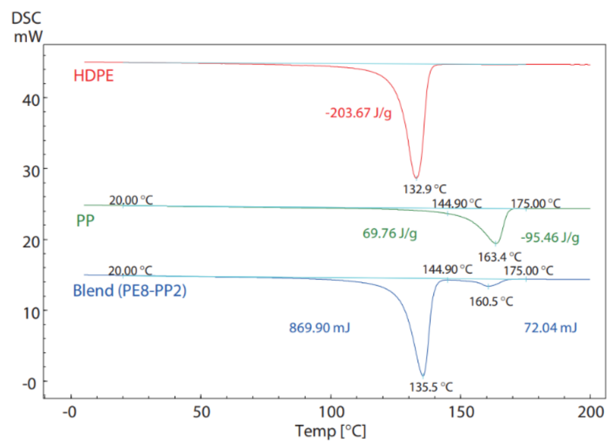

Figure 3:DSC-Plot HDPE and PP.

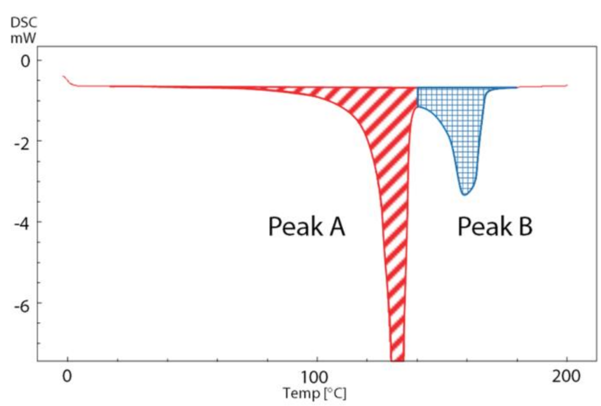

Figure 5: PE-RT/PP Blend Expected DSC Chart.

How to Achieve a Better Morphology?

Our requirement is when the blend of PP and PE is being cooled it remains miscible, it can be held at a temperature such that PP crystallizes from the molten blend. This temperature must be such that PE will not crystallize over the longest time PP takes to crystallize. After a time long enough for PP to completely crystallize the blend is further cooled and the remaining PE will crystallize. This phenomenon results in PP forming a semi-continuous phase in PE, leading to a co-continuous morphology even when PP is the minor phase. This will give a unique phase structure to the blend and it is expected that physical and mechanical properties will be unique to this microstructure. This statement is inferred from the article whom refence is cited[2].

Physical Properties:

PE-RT (Polyethylene Raised Temperature):

- ❖ PE-RT is a type of polyethylene with enhanced temperature resistance compared to standard polyethylene.
- ❖ PE-RT offers cost-effectiveness and processing advantages compared to some other high-performance materials.
- ❖ PE-RT, or Polyethylene of Raised Temperature resistance, is a type of polyethylene with enhanced properties for hot and cold water applications, as well as some industrial uses. Here's a breakdown of its key physical properties:

Mechanical:

High long-term strength: Can withstand pressure for over 50 years at 70°C and 0.4MPa.

Excellent flexibility: Easily bends with small radius (5D) and no rebounding, ideal for construction.

Good impact resistance: Able to withstand external force and low temperatures (-70°C) without needing pre-heating for bending.

Lightweight: Easy to transport and handle.

Noise and water hammer resistance: Absorbs vibrations and reduces noise in plumbing systems.

Thermal:

High thermal stability: Can handle continuous hot water (up to 70°C) without significant degradation.

Freeze-break resistance: Less likely to burst than other pipes when freezing occurs.

PP (polypropylene):

- ❖ PP is a versatile thermoplastic with good chemical resistance, high melting point, and excellent toughness.

- ❖ Polypropylene (PP) is a widely used thermoplastic known for its versatility and impressive physical properties.

Appearance:

Color: Naturally white, but can be pigmented to various colors.

Opacity: Translucent in its natural state, but can be made opaque with fillers.

Texture: Semi-rigid, with a slightly waxy feel.

Good weld ability: Can be easily joined using various welding techniques.

Recyclable: Can be recycled into new products, making it a more sustainable option.

Biocompatible: Generally considered safe for contact with food and medical devices.

Chemical Properties:

PE-RT, or Polyethylene of Raised Temperature resistance:

- ❖ PE-RT, or Polyethylene of Raised Temperature resistance, boasts impressive chemical properties.

Excellent Corrosion and Tuberculation Resistance:

Unlike metal pipes, PE-RT is immune to rust and the build-up of mineral deposits like lime scale.

- Longer lifespan without corrosion-related failures.
- No need for internal coatings or protective measures.
- Reduced maintenance costs compared to metal alternatives.

High Resistance to Chlorine and Chloramine:

PE-RT can handle treated water containing these common disinfectants effectively. This makes it suitable for:

- Municipal water supply systems.
- Swimming pools and water treatment facilities.
- Industrial applications where chlorinated water is used.

Polypropylene:

Non-polar Nature:

PP's molecular structure lacks strong electrical charges, making it non-polar.

Excellent resistance to most acids and bases: Polar molecules like acids and bases struggle to interact with PP due to its lack of charge, making it resistant to their corrosive effects.

Good solvent resistance: Non-polar solvents like oils and greases also have minimal interaction with PP, rendering it resistant to their dissolving power.

Blend of PE-RT (Polyethylene Raised Temperature) and Polypropylene:

Properties:

Polyethylene Raised Temperature (PE-RT) and Polypropylene (PP) are both types of thermoplastic polymers with distinct properties. When blended, their combination may result in a material with a unique set of characteristics. Here are some general properties that you might expect from a blend of PE-RT and PP:

Thermal Stability: PE-RT is known for its elevated temperature resistance, and blending it with PP could enhance the overall thermal stability of the material. This blend might be suitable for applications requiring resistance to higher temperatures compared to standard polyethylene.

Flexibility: Both PE-RT and PP are generally flexible materials. The blend is likely to maintain good flexibility, making it suitable for applications where some degree of flexibility is required.

Impact Strength: Polyethylene typically has good impact strength, and the blend may exhibit similar characteristics.

Processability: Both PE-RT and PP are known for their ease of processing. The blend should be easily processable through common thermoplastic processing methods such as injection molding or extrusion.

Density: The density of the blend will be influenced by the proportions of PE-RT and PP in the mixture. Polypropylene has a lower density than polyethylene, so the blend might have a density between the two materials.

Environmental Resistance: Both polyethylene and polypropylene are known for their resistance to environmental factors such as UV radiation. The blend is likely to maintain good resistance to weathering and outdoor exposure.

Processing Requirements:

When blending polyethylene raised temperature (PE_RT) and polypropylene (PP), there are several processing requirements to consider. The goal is to achieve a homogeneous blend with desirable properties. Here are the key considerations:

1. Compatibility: PE-RT and PP have different chemical structures, so achieving good compatibility between them can be challenging. To enhance compatibility, various techniques can also be employed, such as using compatibilizers or modifying the surface properties of the polymers.

2. Melting Temperatures: PE-RT and PP have different melting temperatures. PE-RT typically has a higher melting temperature than PP. It is crucial to select appropriate processing conditions

that allow both polymers to melt and blend together effectively. This can be achieved by adjusting the processing temperature and time.

3. Mixing Mechanism: To ensure a uniform blend, efficient mixing is essential. This can be accomplished through various methods, such as melt blending using extruders or mixers. Mentioned equipments are already discussed in the above section.

4. Processing Parameters: The processing parameters, including temperature, pressure, and shear rate, play a crucial role in achieving a well-blended PE-RT and PP blend. These parameters should be optimized to ensure proper melting, mixing, and dispersion of the polymers.

5. Additives: Depending on the desired properties of the blend, additives such as stabilizers, compatibilizers, or processing aids may be incorporated. Stabilizers help prevent degradation during processing, while compatibilizers improve the compatibility between PE_RT and PP. Processing aids can enhance the processability of the blend.

Processing Equipment:

To process the blend of PE-RT and PP, several equipment options are available depending on the scale of production and desired processing method. Here are some commonly used equipment for blending PE_RT and PP:

1. Single-Screw Extruder: Single-screw extruders can be used for blending PE-RT and PP to produce our desire blend. They consist of a rotating screw within a heated barrel. Both constituents are fed into the extruder, where they are melted, mixed, and then forced through a die to form the desired shape. This equipment allows for continuous processing and can be used for both small and large-scale production.

2. Twin-Screw Extruder: Twin-screw extruders would be efficient for enhanced mixing of constituent polymers PE-RT and PP .It have higher blending capabilities compared to single-screw extruders. They have two intermeshing screws that provide better distributive and dispersive mixing.

4. High-Speed Mixer: Another option is High-speed mixers, such as high-speed intensive mixers or high-speed rotor mixers, are suitable for blending thermoplastic materials. They use high-speed rotating blades to mix and melt the polymers. High-speed mixers are often used for small-scale production or laboratory-scale blending.

5. Blending Tanks: For smaller-scale production or laboratory experiments, blending tanks can be used. These tanks provide a controlled environment for manually mixing and blending the PE-RT and PP. The polymers are typically heated to their melting points and then mixed using mechanical agitation or stirring.

Testing:

Material Analysis:

Verify the composition and quality of the PE-RT and PP blend used in the pipes.

Check for compliance with material standards and specifications

Hydrostatic pressure test:

This test measures the pipe's resistance to bursting under internal pressure. A water-filled pipe is pressurized until it fails, and the pressure at which it fails is recorded. This test is important so that the pipe can withstand the water pressure in the system. According to ASTM D2837.

Tensile test:

Tensile test records the pipe's resistance to pulling forces. A sample of the pipe material is pulled until it breaks, and the force required to break it is recorded. This test is important so that the pipe can withstand the stresses of installation and use. According to ASTM D 3039.

Density:

This test evaluates the weight of the pipe per unit volume. The density of the pipe material affects its weight and stiffness. According to ASTM D4052

Flexural test:

Measures the pipe's resistance to bending. A sample of the pipe is bent until it breaks, and the angle at which it breaks is recorded. This test access that the pipe can withstand the bending stresses that it may experience during installation and use. According to ASTM D7264/D7264M.

Vicat softening temperature analysis:

The Vicat softening temperature is one of the indexes to evaluate the heat resistance of materials and reflect the physical and mechanical properties of samples under heated conditions. The Vicat softening temperature is tested by the Vicat softening point tester under the force of 50 N and the heating rate of 50°C/h. The specimen is a square with a side length of 10 mm. The temperature ranges from 25°C to 200°C.

Macro mechanical performance:

The tensile properties are tested by the universal test machine with an accuracy of 1 N and a tensile rate of 50 mm/min according to ASTM D638.

Impact resistance:

Impact test estimates the ability to endure sudden impacts. A sample of the pipe is hit with a weight, and the damage to the pipe is assessed. The pipe's ability to withstand accidental impacts during installation and use. According to ASTM D256.

Melt flow index (MFI):

The melt viscosity of the plastic, affects processing and performance. A sample of the pipe material is melted and extruded through a die, and the time it takes for the extrude to flow a certain distance is recorded. This test is important for ensuring that the pipe material can be easily processed into pipes. According to ASTM D1238.

Cost Calculation:

PE-RT cost per pound ≈ 0.6$

PP cost per pound ≈ 0.4$

The final blend contains 80% PE-RT and 20% PP, so the cost of blend would be according to the corresponding percentages of constituents in addition to the processing cost (e.g., electricity consumptions etc. such expenses vary place to place) and the cost of additives used during processing and by incorporating additional expenses.

Following is the estimated cost of raw material required for the preparation of blend.

Blend cost per pound ≈ 0.4*0.2+0.8*0.6= 0.56$

References:

[1] 'REHAU RADIANT HEATING SYSTEMS DESIGN GUIDE'. [Online]. Available: www.rehau.com

[2] R. A. Shanks, J. Li, and L. Yu, 'Polypropylene-polyethylene blend morphology controlled by time-temperature-miscibility'.